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Effective Health Care

Bulletin on the effectiveness of health service interventions for decision makers

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Hospital volume and health care outcomes, costs and patient access

- There are some pressures for acute services to be concentrated in hospitals with larger volume.
- Much research examining the relationship between hospitals or clinician volume and health outcomes is of poor quality and does not make adequate adjustment for differences in patient case-mix.
- The best research suggests that there is no general relationship between volume and quality. However, in some specialities there appear to be quality gains associated with increased hospital or clinician volume.
- There is no evidence that cost savings can be secured merely by increasing scale in acute hospitals beyond 200 beds and it is likely that large hospitals (above 600 beds) display diseconomies of scale, though these inefficiencies may be offset in other ways.
- There is evidence that utilisation of some health services is lower for patients living further away. When services are concentrated, some of the costs are shifted from the health service to patients and their carers.

A. Background

Within the NHS, purchasers and providers are facing pressures for further concentration in the provision of hospital services. Interviews carried out by University of York researchers indicate that these include the combined effect of changes in medical staffing and training such as the reduction in junior doctor hours, service and training recommendations of the Royal Colleges and professional associations and reforms in the structure of medical training introduced in April 1996.

Other drivers include the imperative on Trusts to achieve target reductions in management costs and more general pressures on Health Authorities and Trusts to reduce the unit cost of health services through efficiency savings. Concentration of services through Trust merger or service rationalisation has often been seen, possibly mistakenly, as a way of achieving both of these goals.

This bulletin summarises the results of systematic reviews carried out at the University of York to assess research into the possible relationship between volume of clinical activity in hospitals and the quality of health care outcomes, hospital costs (economies of scale) and patient access. It aims to inform decision makers facing choices about the configuration of services such as rationalisation or Trust mergers where concentration of hospital services in to larger hospitals has been proposed as a means of improving the quality or efficiency of health care. Full reports of these reviews are available from the NHS Centre for Reviews and Dissemination.[1-5]

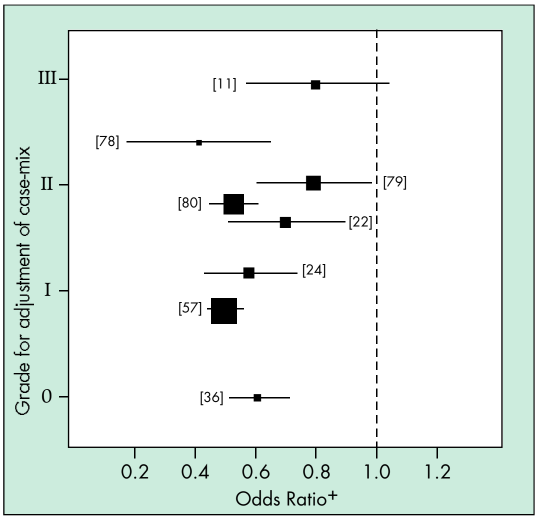

Fig. How estimates of benefit of increased volume (>200) of CABG surgery vary by adequacy of adjustment for case-mix.

\+ Odds Ratio <1 indicates reduced hospital mortality in hospitals carrying out >200 CABGs per annum

B. Volume and outcomes

There is considerable interest in whether improved health care outcomes can be gained from concentrating the hospital care of particular conditions or procedures. This may involve fewer clinicians or hospitals providing higher volumes of activity. Against this background, a systematic review of the research was conducted in order to assess the evidence for a relationship between hospital or doctor volume and patient outcomes.[2]

More than 200 (mainly observational) studies were included, most reported a reduction in poor health outcomes (principally hospital mortality) as volumes increased. The apparent strength of this observation may be misleading though, because of the inadequate handling in many studies of differences in patient case-mix between hospitals and doctors.

Adjustment for case-mix

Studies of hospital mortality rates need to distinguish between the effects of differences in severity of illness and differences in quality of care. Higher mortality rates may be due to a higher proportion of emergency or urgent cases, whereas lower mortality rates may reflect the better results obtained from treating a lower-risk patient population. Variations in case-mix have a crucial influence on the interpretation of outcome data based on observational studies. Unmeasured differences in patient populations between hospitals or doctors with different volumes result in misleading results (confounding).[6]

The more that patient characteristics which influence health outcome are taken into account, for example by statistical adjustment, the more likely it is to obtain an unbiased assessment of the association between hospital or physician volume and outcome.[7] Routine hospital data rarely provide enough detail to adjust adequately for case-mix. Studies which adjust for risk of death based on detailed clinical data are the most valid.

The importance of adequate adjustment is well-illustrated in studies of coronary artery bypass graft surgery (CABG) and also intensive care. In the case of CABG, the size of the relationship between low volume (<200 procedures/year) and increased mortality is reduced in studies which better adjust for differences in patient risk (Fig.).[8] In the case of adult intensive care in the UK, where well-validated prognostic indicators have been developed (APACHE II), higher mortality found in smaller intensive care units using unadjusted data were no longer significant after adjusting for case-mix. The average severity level was higher in patients admitted to smaller units.[9]

Only one study identified used a randomised controlled trial design to evaluate the effect of clinician volume differences in comparable groups of patients.[10] In this study of 50 patients at two university hospitals, no differences in clinical outcome (or total costs) were observed between the two groups receiving angioplasty.

Most studies identified did not sufficiently take into account the effects of differences in patient case-mix. See Appendix for details of studies which adjusted more adequately (Grade III). In these, the size of the relationship between volume and outcome (principally mortality) is reduced, or even disappears, compared to unadjusted data, although it is still significant in several cases (Table 1).

The research is also limited by the narrow measures of outcome used, usually inpatient or 30-day mortality. Differences in mortality rates found may also reflect other factors such as discharge policies rather than quality of care. The interpretation of this sizeable literature is also complicated by the variable definitions of high and low volume both within and across procedures and the range of statistical techniques used to estimate any relationship.

Research has mainly concentrated on the number of procedures carried out in a hospital rather than on the number performed by each clinician. Any true observed relationship between volume and outcome may be related to the volume or experience of the clinician carrying out the procedure, or alternatively it may be related to a whole host of variables such as operating room staff and surgical techniques used.

Finally, a positive relationship between high volume and improved outcome can be interpreted in various ways. It might support the 'practice makes perfect' hypothesis[39] or a 'selective referral' hypothesis, in which hospitals or doctors with good outcomes attract more patients. It may also be the case that higher-volume hospitals attract better clinicians or support staff so producing a hospital level effect. Thus it is difficult using observational studies to uncover the inter-relationships between the many variables and the direction of any causality.

Table 1 Summary of evidence of volume quality relationship from best quality studies*

Procedure/Service/ Condition	Evidence
Coronary artery bypass graft surgery	• Reduced risk of in-hospital mortality in hospitals carrying out >200 procedures/year (OR = 0.84).[8](See Fig.)
Paediatric heart surgery	• Reduced death rate in hospitals with >300 cases per year compared to hospitals with <10 cases and <300 cases. (OR 1/8 and 1/3 respectively).[14]
Acute myocardial infarction	• No significant difference in in-hospital but higher 6 months mortality and lower rate of re-infarction in hospitals with <300 beds (mortality 17% vs 12%).[15] • Significant negative relationship between in-hospital mortality and physician volume (coefficient = -0.05) but not hospital volume.[13]
Cardiac catheterisation	• No physician volume relationship found. Mortality declines by 0.1% for a 100 increase in annual number of hospital procedures (average N of treatments = 400).[13]
Percutaneous transluminal coronary angioplasty	• No significant association between physician volume and angiographic or clinical success.[10] • Reduction in major complications when volume > 400/year (OR = 0.66).[18] • No physician volume relationship found for mortality, but more complications, emergency CABG and longer length of stay in physicians carrying out <50 procedures per year.[17]
Abdominal aortic aneurysm	• SMR 30% higher in hospitals with <14 patients/year, but no surgeon relationship found.[19] • 12% mortality for hospitals with <6 procedures compared to 5% in those >38 per year. Double the mortality in low volume surgeons (<6) compared to high volume surgeons (>26).[20] • Mortality declines by 1% for an increase of 4 operations per year per hospital (average N of treatments = 23 per year). No evidence of a surgeon volume effect.[16] • 2% increased odds of dying if in hospital with <21 cases compared to >21. This risk difference greater for ruptured aneurysms.[21]
Amputation of lower limb (no trauma)	• SMR 16% higher in hospitals with below average annual volume (Average N of treatments = 10.5).[19]
Gastric surgery	• No significant difference between hospitals with below and above average annual volume (average N of treatments = 24).[19] • Mortality declines by 1% for a 17 increase in the annual number of hospital operations (average N of treatments = 38).[16] • Surgeons carrying out <1 procedures annually associated with higher mortality rate than those doing >1.[22] • No relationship between physician volume and mortality (average N of treatments = 8).[16]
Cholecystectomy	• SMR 26% higher in hospitals with below average annual volume (average N of treatments =109).[19] • Hospitals performing <168 procedures a year had a mortality rate of 1.52% compared to 1.21% in those with higher volume. No further reduction in mortality observed for next highest volume category. No significant association with surgeon volume found.[22]
Intestinal operations (excluding cancer)	• Hospital mortality higher (8.3%) when <40 operations performed a year than if >40 ops (5.9%). Surgeons with annual volume >8 also associated with lower mortality.[22]
Gall bladder diagnosis (non-surgical)	• SMR 14% lower in hospitals with below average annual volume (average N of treatments = 73).[19]
Ulcer (non-surgical)	• No statistically significant effect of volume.[19]
Knee replacement	• Higher hospital volume associated with lower risk of complications (average N of treatments = 3.5).[23]
Hip fracture	• No significant effect of hospital volume on mortality (average N of treatments = 45).[19]
Neonatal care	• Infants <28 wks gestation had better survival in intensive care units (>500 days of ventilation/year) compared with special care units (<500 days of ventilation/year). No difference for more mature infants.[25]

Table 1 Continued

Procedure/Service/ Condition	Evidence
Paediatric intensive care	• No statistically significant association found between mortality and monthly volume.[26]
Adult intensive care	• No association between % dying and monthly unit volume.[9]
Prostatectomy	• No statistically significant differences found.[27]
Trauma care	• No statistically significant difference in mortality from major trauma between high and low volume A&E departments with volumes ranging from <10/yr to >90/yr in 3 regions.(Further analysis of data from study by Nicholl et al, 1995)[37] • No difference in mortality in a tertiary trauma unit for patients with mainly blunt injuries as it doubled in volume over a 4-year period.[28]
Cataract surgery	• Surgeons carrying out >200 ops per year had greater rate of adverse events (esp posterior capsular opacification OR = 2.5).[29]
AIDS	• Risk of 30-day mortality was 2.5 times as high when treated in low experience hospitals (<43 patients) than in a hospital having treated >43 patients (RR for 30 day mortality = 2.5).[30]
Breast cancer	• 15% reduction in mortality with surgeons treating >29 new cases/year, but no advantage of >50 compared to >29.[31]
Colon and rectal cancer	• SMR 20% higher in hospitals with below average annual volume (average N of treatments = 17).[19] • No significant association between volume and in-hospital mortality (average N of treatments = 50) or surgeon volume (average N of treatments = 8).[16]
Laparotomy with colorectal resection (for cancer and non-cancer diagnoses)	• No statistically significant differences in mortality or morbidity between surgeons with volumes ranging from 44 to 110 cases per year.[32]
Stomach cancer	• No statistically significant association between mortality and either hospital or surgeon volume.[16]
Malignant teratoma	• 5-year mortality 60% lower in patients treated at a cancer unit which treated over 50% of patients with this cancer in the area.[33]
Oesophageal cancer	• 17% lower rate of operative mortality in surgeons performing ≥3 ops annually. 4% reduction in 5-year mortality with surgeons treating ≥6 new cases per year. Most explained by reduced operative deaths.[34]
Pancreatic cancer	• Patients treated by surgeons with highest volume (76 cases in 20 months) had lowest risk of complications (fistula) compared to lower volume surgeons in the same hospital.[35]

* All outcomes in this table are adjusted for case-mix. Results of studies with less adequate adjustment for case-mix (Grade II and below) are not summarised here but are available in the full report.[2] Mean volumes stated if reported in the paper

OR: Odds Ratio (the ratio of the odds of an adverse event occurring in a higher volume unit compared to a low volume unit; if the OR <1 then there is less risk of a poor outcome in the higher volume unit).

Two conclusions can be sustained from the existing literature on volume and outcome. Firstly, that the bulk of the research, because it does not sufficiently take into account case-mix differences, probably overestimates the size of impact of volume on the quality of care. Secondly, because none of the research indicated that increasing the volume of activity over time resulted in changes in health outcomes,[24,28] it is difficult to use findings of a positive relationship between volume and outcome across hospitals or doctors to infer what would happen to health care outcomes if existing low volume units expanded.

An indication of how activity levels in English Trusts compare with the thresholds derived from the best quality studies which suggest a cut-off is shown in Table 2.

These thresholds may still be subject to bias and, because many are from other countries and some from earlier time periods, may not be directly applicable to the NHS.

This review did not explicitly address the possible relationship between the degree of specialisation of clinicians and quality of care or the related issue of multi-disciplinary links. Where specialisation improves quality, then this will require care to be provided in a more coordinated way and, particularly for rarer conditions, sometimes in larger centres. The need may be met however, in the more common conditions by a clearer division of labour within hospitals and links across hospitals rather than concentration of services in fewer hospitals.[40]

C. Volume and costs

It is often assumed that by concentrating hospital services into larger units, efficiency will be improved because of the operation of economies of scale. However, it is important to validate empirically the range of output over which average costs are expected to fall, and the scale at which costs may begin to rise.

Economies of scale refers to a situation in which long-run average costs fall as the scale or volume of activity rises. Economies of scale are expected to be present where the fixed costs of providing a service are relatively high. For example, if a large investment in human and physical capital is required in order to produce any level of output, the cost of this investment is a fixed cost. As output increases, average costs will fall (over some range) as fixed costs are spread over larger volumes. However, increasing scale often brings additional sources of cost, and beyond some critical volume average costs are expected to begin to rise because of diseconomies of scale.[41]

Against this background, a systematic literature review (available in a full CRD report)[3] was undertaken to critically appraise the evidence on

Table 2 Volume thresholds from best studies and current activity in NHS Trusts +

Procedure [OPCS4R codes]	Annual hospital volume threshold	Annual doctor volume threshold	% of Trusts in England below hospital volume threshold [n]	% of procedures in England carried out in Trusts with below hospital volume threshold [n]
Coronary artery bypass graft surgery [K40-K44]	200		20% [7]	0.04% [8]
Percutaneous transluminal angioplasty [K49]	400	50	71% [30]	41% [4357]
Cholecystectomy [J18]	168		56% [125]	36.7% [13635]
Breast cancer surgery [B27-28, B29-37 & ICD9 = 174]		29	12% [28] @	1% [264] @

These data should be interpreted with caution: since Trusts may contain more than one hospital, procedures may be carried out on more than one site by several doctors and doctors may work in more than one Trust.

+ Source: Hospital Episode Statistics 1994/5

* Based on only studies which provide discrete thresholds in Table 1

@ Based on doctor volume threshold but data at level of hospital

economies of scale. Over 100 relevant studies were identified employing a range of statistical and other techniques of varying methodological quality. Study validity is also likely to be affected by problems of adjustment for case-mix since comorbidities are important in determining patient costs.[42]

Overall, the results from the more reliable studies are largely consistent: if economies of scale are evident, they appear to be fully exploited in acute hospitals with 100–200 beds; hospitals with more than 300–600 beds display diseconomies of scale. In other words, hospitals below 100–200 beds may improve efficiency by increasing size, but expanding above this range will not necessarily reduce average costs and if too large, may increase average costs.

An issue of interest is whether increasing concentration by, for example, hospital mergers can be expected to generate efficiency gains in the NHS through the exploitation of economies of scale. The literature which deals directly with gains from merger (mostly from the USA) has not generally shown dramatic improvements in operating practices[43] or expected savings.[44-46,77] If, as the research evidence suggests, economies of scale are exhausted at relatively low levels, mergers cannot be expected to offer opportunities for improvements in efficiency when the constituent hospitals are already above the threshold level.

This result may seem counter-intuitive: it is often assumed that one hospital must be more efficient than two smaller ones as duplication of management at the very least, may be eliminated. However, this may not be the case: it is possible that more management is required to run a large organisation than two small ones. More fundamentally, it is the **total** cost per episode and not just the management cost that is important, and that has been studied in the literature. Even where larger hospitals have fewer managers, they may not gain in efficiency. This may be due to a decline in standards of management leading to reduced efficiency, or to a redistribution of management tasks to non-traditional managers, so reducing output. To examine this question properly would require studies which considered simultaneously both the cost and outcomes data.

Table 3 puts these results in an English context. However, a number of caveats must be emphasised in applying these results. Firstly, the review has evaluated cost economies in the production of acute services and not examined the optimal scale for sub-acute services (e.g. in cottage hospitals). No relevant literature was identified examining economies in training. Secondly, the literature on economies of scale is directly relevant only to those hospitals which are technically efficient. Where hospitals are characterised by excess capacity and unused facilities, concentration may (but need not)[77] be an efficient means of reducing overall unit costs by reducing surplus capacity or an expeditious way locally to restructure health services.[47]

The evidence from the review of volume-quality links in section B shows that for some specialties there may be quality gains from increased volume. There might also be inter-specialty links that improve quality (research evidence in this area is scant). Together these may imply quality gains from hospital scale that compensate for reduced efficiency.

In the light of these caveats, the principle, tentative, conclusions from the literature review are that there is no evidence that cost savings can be secured merely by increasing scale beyond 200 beds and that it is likely that large hospitals (above 600 beds) suffer from inefficiencies – though these may be offset in other ways.

D. Patient access

The potential effects of concentration of hospital services on patient access are also important to consider. The systematic review (available as a full CRD report)[4] identified 47 studies of patient access which in general provide poor quality evidence. The research in this area focuses almost exclusively on the relationship between observed rates of utilisation and distance (or

Table 3 Distribution of English acute hospitals by size (including acute sites in combined Trusts)

Number of beds	Number of hospitals (acute)	% Total hospitals (acute)	Number of beds (acute)	% Total beds (acute)
<100	90	22.0	5002	3.05
100-200	59	14.4	8491	6.0
200-300	51	12.5	12513	8.9
300-400	55	13.4	19260	13.7
400-500	48	11.7	21147	15.0
500-600	39	9.5	21224	15.1
>600	67	16.4	53320	37.8

Source: IHSM Health and Social Services Yearbook 1996/7.
International research suggests that cost-per-case is minimised in hospitalas with less than around 300–600 beds and more than100–200 beds, assuming such hospitals are operating efficiently.

travel time) as a proxy for access. This is, at best, a partial approach because distance is only one of a number of likely factors (e.g. opening hours, personal mobility, gender, language or socio-economic group) affecting access. In addition, most of the studies identified were cross-sectional and were poorly controlled for the effects of confounding variables.

Bearing in mind the important qualification on the quality of many of the studies, the review suggests that: there is evidence of a reduction in access with distance (distance-decay) particularly in areas where perceptions of need and importance may be low (e.g. mammography,[48] cervical cytology[49] and alcoholism aftercare[53])[54] but also self-referral to A&E departments.[50-52] One study showed that positive systematic action such as a call-and-recall system improved use of a centralised screening programme in the UK.[50] Distance may not affect attendance where the clinic is related to cancer.[56]

There is conflicting evidence for inpatient services present in research from North America,[57-62] whilst that from the UK finds evidence of distance-decay in each case.[53,63-67] Although not conclusive, the evidence is consistent with the view that accessibility is likely to be adversely affected by the distance from the hospital. However, these studies often poorly adjust for factors like severity and need. A few studies have reported reductions in the frequency of patient visiting as distance from the hospital increases.[68-70]

There is mixed evidence about the impact of distance on health outcome. Mortality from asthma,[71,72] diabetes and perinatal mortality is increased with distance[72] but not for a range of other diseases such as breast and cervical cancer (UK study)[72] or serious road traffic accidents (Norfolk study).[73] In Finland, a study showed that concentration of a radiotherapy facility did not adversely affect survival rates from breast or prostatic cancer.[74] However, a French study reported that people in more isolated rural areas had a more advanced stage of colorectal cancer when diagnosed.[75]

Where services are concentrated, the effect can be to shift some of the costs of health care from the NHS to patients and their carers.[76] For example, people needing radiotherapy for cancer and who have no independent cheap transport may spend all day getting to and from a cancer centre.[56] In assessing the effects of increased concentration on access and utilisation, the implications of cost-shifting, particularly on disadvantaged groups, should not be overlooked.[48]

E. Implications

The literature on links between volume of activity and clinical outcomes suggests that for some procedures or specialities there may be some quality gains as hospital or clinician volume increases. In other areas the research suggests an absence of significant volume gains. Generalisation is clearly not possible on the basis of these results. Hence it would not be warranted to extrapolate the findings, whether positive or negative, outside the sample ranges, or for the many procedures where the research evidence is too poor to suggest any conclusion.

Where volume is associated with quality, the direction of causation is not established and there is no good evidence to indicate that increasing volume will actually result in an improvement in health care outcomes. Nevertheless, in the few cases where volume quality links have been suggested by more reliable studies, these might well act as prompts for investigation by purchasers and/or clinicians. In some cases, the indicated thresholds are relatively low, and could be reached through specialisation of tasks within a hospital rather than an increase in the size of the provider.

If service concentration, justified on the basis of clinical outcomes, is proposed there is a need to understand the source of expected benefits. For example, if the main driver of improved outcome is the experience of clinicians, this may justify specialisation of tasks within a clinical team, it may justify larger units, or it may simply suggest that clinicians need to work across sites. Each case must be examined to see if a solution can be found that reaps any volume-related quality gains in excess of financial, access or equity costs.

Optimal configuration of services will depend upon the volume–quality links suggested for the relevant specialties, together with inter-specialty links. Also taken into account will be the impact that scale may have on costs (as both scale and market dominance may breed inefficiency), on access, on equity and upon responsiveness (which may depend upon choice). The results summarised in sections C and D may be helpful in balancing these considerations.

Since medical staffing issues may be a major driver for concentration, purchasers need to take an active interest in medical staffing issues.

Those proposing or considering proposals for change may find the following questions helpful:

- What cost savings or improvements in health care outcomes are expected to result from the proposed merger or service rationalisation (and can these be achieved by other means)?
- What procedures will be put in place to ensure that benefits are realised and to what extent are community services sufficient to support this?
- What are the costs in terms of reduced access and choice for patients and purchasers and how will they be ameliorated?
- Has a baseline been established against which to monitor changes in health care outcomes, costs, output levels and patient access and how will these be measured?

Appendix: Volume and outcome relationship: Grade III Studies

All the studies identified were graded on a 4-point scale from 0–III where 0 indicates no adjustment, I adjustment for age and sex only, II for some clinical risk factors and III indicates more extensive adjustment using validated clinical risk factors or scores.

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	Case-mix adjustment	Results
Coronary artery bypass graft surgery (CABG)						
Hannan et al (1994)[11] and (1995)[12] USA	57187 patients undergoing CABG surgery in 30 New York hospitals by 528 surgeons	Analysis of the Cardiac Surgery Reporting System (a comprehensive prospective clinical database) 1989 – 1992	In-hospital mortality	Hospital volume ranged from 28 to 1340 procedures per year Surgeon volume: <50 51 – 100 101 – 150 >151	42 potential risk factors, including demographic data, admission status, preoperative complications Logistic regression	In 1989 lowest volume hospital mortality was 5.45 and highest volume was 3.77. In 1992 lowest volume hospital mortality was 7.65 and highest volume was 1.86 The ratios of the adjusted mortality rates for <50 operations to >151 operations decreased from 1.89 in 1990 to 1.36 in 1992 In 1991 and 1992 there were no significant differences in adjusted mortality rates among any of the volume groups
Kelly & Hellinger (1987)[13] USA	3883 patients undergoing CABG in 26 short-term hospitals by 99 physicians	Retrospective analysis of patient discharge abstracts from the Hospital Cost and Utilisation Project 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 356 (sd 320) Mean physician volume = 109.2 (sd 65)	Age, sex, number of diagnoses and disease stage Multivariate regression	The volume of procedures was negatively associated with adjusted in-hospital mortality (coefficient = -0.005, p = 0.05). Physician volume was not significantly associated with in-hospital mortality
Paediatric heart surgery						
Jenkins et al (1995)[14] USA	2833 children undergoing surgery for congenital heart disease in 37 acute care hospitals	Retrospective analysis of discharge abstract data from California and Massachusetts 1988 and 1989	In-hospital mortality and length of stay	Annual volume: <10 10 – 100 101 – 300 >300	Age, sex, race, transfer status, cardio-pulmonary bypass code, complexity of the procedure Multivariate regression	Adjusted LOS was longer by 1.6 days at hospitals with <10 cases (p = 0.08), 3.6 days (p = 0.001) at hospitals with 10 - 100 cases and by 3.3 days (p = 0.0001) at hospitals with 101 - 300 cases in comparison with facilities treating >300 cases Compared with hospitals >300 cases the estimated odds ratio for mortality was 7.7 (95% CI: 1.6 - 37.8) for patients at hospitals with <10 cases, 2.9 (95% CI: 1.6 - 5.3) with 10 to 100 cases (p<0.0005) and 3.0 (%% CI: 1.8 - 4.9) with 101 - 300 cases

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	Case-mix adjustment	Results
Acute myocardial infarction and other heart problems						
Barbash et al (1994)[15] 13 countries	8206 patients with acute myocardial infarction, receiving thrombolytic therapy in 438 hospitals	Retrospective analysis of the multinational database of the International Tissue Plasminogen Activator/Strepto kinase Mortality Trial 1988 – 1989	Mortality, reinfarction, bleeding complication, stroke and LOS	The hospitals were classified as having and not having coronary revascularisation and further sub-divided into < 300 beds and >300 beds	Sex, age, angina pectoris, previous myocardial infarction, diabetes, history of hypertension, smoking, poor haemodynamic state at admission Logistic regression	No significant difference in in-hospital mortality between the hospitals. 6 months mortality was significantly higher in patients admitted to small centres with revascularisation facilities (17% v 11.8 % to 12.3%, p = 0.03) Rate of reinfarction was lowest in small centres with revascularisation services (1.7 v 3.6, 3.9, 4.9, p = 0.01) and the rate of haemorrhage was lowest in large centres without revascularisation services (4.9 v 7.1, 6.0, 7.1, p = 0.01). Stroke rate did not differ significantly between centres
Kelly & Hellinger (1987)[13] USA	11033 patients with acute myocardial infarction (no surgical procedure) in 146 short term hospitals by 926 physicians	Retrospective analysis of patient discharge abstracts from the Hospital Cost and Utilisation Project 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 146 (sd 96) Mean physician volume = 30 (sd 26)	Age, sex, number of diagnoses and disease stage Multivariate regression	Negative relationship between adjusted in-hospital mortality and physician volume (coefficient = –0.049, p = 0.05). No statistically significant relationship between hospital volume and adjusted mortality was found
Cardiac catheterisation						
Kelly & Hellinger (1987)[13] USA	4835 patients undergoing cardiac catheterisation in 39 short term hospitals across the US by 145 physicians	Retrospective analysis of patient discharge abstracts from the Hospital Cost and Utilisation Project 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 399 (sd 401) Mean physician volume = 97 (sd 71)	Age, sex, number of diagnoses, disease stage and complications Multivariate regression	After adjustment mortality was associated with hospital volume (coefficient = –0.001) but not physician volume
Coronary angioplasty						
Kimmel et al (1995)[18] USA	19594 patients undergoing a first balloon angioplasty in 48 cardiac catheterisation laboratories	Retrospective analysis of the Society for Cardiac Angiography and Interventions Registeries 1992 and 1993	In-hospital mortality, emergency bypass surgery, myocardial infarction and major complication	Volume was defined in 3 ways: 1) < 200 200 – 399 > 600 procedures per year 2) < 200 ≥ 200 (current ACC/AHA guidelines) 3) as continuous variable	A large range of clinical demographic data Logistic regression	After adjustment a significant inverse relationship between volume and emergency CABG (p<0.001), acute MI (p<0.001) and major complication (p<0.001) was found. No statistically significant relationship between volume and mortality A significant decrease in major complication was observed when volume was greater than 400 procedures per year (adjusted OR 0.66, 95% CI: 0.46 – 0.96)
Shook et al (1996)[17] USA	2204 patients undergoing PTCA by 38 operators	Retrospective analysis of computerised case records 1991 – 1994	CABG <24 hours after PTCA, complica-tions, in-hospital mortality and LOS	Operator volume: High: >50 cases per year Low: <50 cases per year	Age, sex, race, body surface area, procedural priority, procedural complexity, resting heart rate, blood pressure Logistic and linear regression	Risk adjusted mortality did not differ. Low volume operators required more emergency CABG (RR 2.05, 95% CI: 1.24 to 3.39, p=0.005), had higher complication rates (RR 1.79, 95% CI: 1.32 to 2.43, p<0.001) and a 9% longer length of stay (RR 1.09, p=0.004) than high volume operators
Talley et al (1995)[10] USA	50 patients undergoing elective PTCA for a single lesion in 2 university affiliated hospitals	RCT (concealed allocation) to either a 0.010 or 0.014 PTCA balloon catheter and secondary randomisation to operators of different experi-ence year not given	Angiographic and clinical success	Physicians trained in interventional cardiology and had independently performed >500 procedures or to a fellow in interventional cardiology who had performed <50 procedures	Baseline clinical and angiographic characteristics were comparable Ordinary least squares regression (intention to treat)	There were no significant differences in either angiographic (100 v 96%) or clinical success (100 v 96%) between the low and high volume operators. Low volume operators had an increase in the time to cross the lesion and fluoroscopic time and a trend in total procedure time

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	Case-mix adjustment	Results
Abdominal aortic aneurysms						
Flood et al (1984)[19] USA	9532 patients undergoing intrabdominal artery operations in 645 acute care hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year (15)	A range of demographic, biochemical, physiological and severity variables Patients put into 3 risk categories Logistic regression	The SMR for low v high volume hospitals was 1.20 v 0.91 (p<0.001) For low, medium and high risk patients SMRs were above 1 in low volume hospitals and below 1 in high volume hospitals (results presented graphically)
Veith et al (1991)[20] USA	3570 patients undergoing abdominal aortic aneurysm repair (unruptured): by 98 surgeons	Retrospective review of New York Statewide Planning & Resource Cooperative System database 1985 – 1987	Mortality	Annual hospital volume: 1–5 >38 (average =10) Annual surgeon volume: 1–5 >26 (average=4)	Age, comorbidities and stage of disease Chi-square test	Adjusted mortality for low volume hospitals was 12% v 5% for high volume hospitals (p<0.001) and for low volume surgeons was 9% v 4% for high volume surgeons (p<0.001)
Katz et al (1994)[21] USA	10014 patients aged 50 and above with a diagnosis of abdominal aortic aneurysms (intact = 8185 and ruptured = 1829) in over 175 acute care hospitals	Retrospective analysis of the Michigan Inpatient database 1980 – 1990	Mortality	Volume was defined for intact AAA as: 0 1 –10 11 – 20 >21 and for ruptured AAA as: 0 1 – 4 > 5	Age, sex, race, and comorbidity Logistic regression	Hospital volume under 21 v over 21 procedures was significantly associated with mortality (OR 1.2, p=0.02) in intact AAA Low surgical volume was significantly related to increased mortality (53.6% compared with 45.7%, p=0.002 [OR not given]) for ruptured AAA
Kelly et al (1986)[16] USA	999 patients undergoing surgery for abdominal aneurysm in 77 short term general hospitals by 232 physicians	Retrospective analysis of data from the Hospital Cost and Utilization Project, based on discharge abstract records 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 23 (sd 12) Mean physician volume = 9 (sd 7)	Age, sex, number of diagnoses and stage of illness Logistic regression	Hospital volume was inversely correlated with mortality (coefficient = -0.0026, p=0.05) The volume of procedures performed by individual physicians did not have a statistically significant effect on mortality
Amputation of Lower Limb						
Flood et al (1984)[19] USA	10267 patients undergoing amputation of the lower limb in 973 acute hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year categorised by level of risk Patients in hospitals with less than or more than the mean hospital volume (11)	A range of demographic, biochemical, physiological and severity variables Patients put into 3 risk categories Standardisation and logistic regression	Overall mortality was 14.4% The SMR for low v high volume hospitals was 1.11 v 0.94 (p<0.05) For all patients in low volume hospitals the SMRs were above 1 and were lowest for high risk patients, and below 1 for all patients in high volume hospitals and, were lowest for medium risk patients (results presented graphically)
Gastric surgery						
Flood et al (1984)[19] USA	26688 patients undergoing operations for ulcers in 1100 acute hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year, categorised by level of risk Patients in hospitals with less than or more than the mean hospital volume (24)	A variety of demographic, physiological, biochemical and severity variables Patients put into 3 risk categories Standardisation and logistic regression	Overall mortality was 4.3% A non statistically significant difference in the SMR for low v high volume hospitals (1.05 v 0.97)

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	Case-mix adjustment	Results
Gastric surgery continued						
Hannan (1989)[22] USA	1342 patients undergoing partial gastrectomy in 216 hospitals by 828 physicians	Retrospective analysis of New York State discharge abstracts from the Statewide Planning and Research Cooperation System 1986	In-hospital mortality	Hospital volume: ≤ 5, 6 – 8, 9 –14, 15 – 36 physician volume ≤ 1 > 1	Age, sex, race, admission status, up to 4 secondary diagnoses and procedures, and severity of illness Logistic regression	Physician volume correlated with adjusted mortality: low volume physicians risk adjusted mortality was 13.60 vs 9.60% for high volume physicians (p<0.01). Patients treated by low volume physicians in hospitals with ≤5 cases had adjusted mortality rate of 17.5% vs 12.3% for low volume physicians in high volume hospitals
Kelly et al (1986)[16] USA	1742 patients undergoing a stomach operation for ulcer in 98 short term general hospitals by 382 physicians	Retrospective analysis of data from the Hospital Cost and Utilization Project, based on discharge abstract records 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 38 (sd 23) Mean physician volume = 8 (sd 0.37)	Age, sex, number of diagnoses and stage of illness Logistic regression	An inverse correlation between hospital volume and adjusted mortality. Each additional 17 operations performed decreased the probablity of death by 1% (p=0.01) Physician volume did not have a statistically significant effect on adjusted mortality
Cholecystectomy (and other gallbladder operations)						
Flood et al (1984)[11] USA	130749 patients undergoing gallbladder operations in 1196 acute hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year, categorised by level of risk Patients in hospitals with less than or more than the mean hospital volume (109)	A variety of demographic, physiological, biochemical and severity variables Patients put into 3 risk categories Standardisation and logistic regression	Overall mortality was 1.1% The SMR for low v high volume hospitals was 1.19 v 0.93 (p<0.005)
Hannan et al (1989)[22] USA	25091 patients undergoing total cholecystec-tomies in 253 hospitals by 2322 physicians	Retrospective analysis of New York State discharge abstracts from the Statewide Planning and Research Cooperation System 1986	In-hospital mortality	Hospital volume: <53 54 – 102 103 – 130 131 – 168 169 – 220 221 – 400 Physician volume: (not given)	Age, sex, race, admission status, up to 4 secondary diagnoses and procedures, and severity of illness Logistic regression	For hospitals performing 168 procedures or less per year the adjusted mortality rate was 1.52% vs 1.21% for hospitals performing more than 168 procedures Physician volume was not significantly related to mortality
Intestinal surgery						
Hannan et al (1989)[22] USA	10297 patients undergoing partial colectomies in 250 hospitals by1997 physicians	Retrospective analysis of New York State discharge abstracts from the Statewide Planning and Research Cooperation System 1986	In-hospital mortality	Hospital volume: <18 19 – 40 41 – 100 101 – 170 171 – 278, Physician volume: < 8 > 8	Age, sex, race, admission status, up to 4 secondary diagnoses and procedures, and severity of illness	Hospitals with an annual volume of 40 cases or less had a risk adjusted mortality rate of 8.3% vs 5.9% for hospitals with volumes above 40 For each hospital volume range, high volume physicians had lower risk adjusted mortality rates than low volume physicians, the ratio of these percentages was 1.26 (p=0.05)
Non-surgical gallbladder diagnosis						
Flood et al (1984)[19] USA	88839 patients with a non-surgical gallbladder diagnosis in 1210 acute hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year, categorised by level of risk Patients in hospitals with less than or more than the mean hospital volume (73)	A variety of demographic, physiological, biochemical and severity variables Patients put into 3 risk categories Standardisation and logistic regression	Overall mortality was 2.8% The SMR for low v high volume hospitals was 0.90 v 1.04 (p<0.05)

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	Case-mix adjustment	Results
Non-surgical ulcer diagnosis						
Flood et al (1984)[19] USA	138268 patients with a non-surgical ulcer diagnosis in1214 acute hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year, categorised by level of risk Patients in hospitals with less than or more than the mean hospital volume (114)	A number of demographic, physiological, biochemical and severity variables Patients put into 3 risk categories Standardisation and logistic regression	Overall mortality was 2.4% The SMR for low v high volume hospitals was 1.02 v 0.98 (n.s)
Knee replacement (arthroplasty)						
Benjamin (1995)[23] USA	324 aged Medicare patients undergoing knee replacement in 310 hospitals	Retrospective analysis of Medicare data collected as part of the Knee Replacement Patient Outcomes Research Team (PORT) 1985 – 1989	Length of stay, post-operative complica-tions	Volume was specified as a continuous variable Mean = 4 (sd 1.0)	Age, sex,socio-economic status, pre-operative health measured by a comorbidity index, type of knee replacement Regression analysis	Higher volume hospitals had a lower probability of a complication (–0.4141) and after adjusting for this a shorter length of stay (–0.0633, p<0.01)
Hip fracture						
Flood et al (1984)[19] USA	52368 patients with hip fracture in 1169 acute hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities study 1972	In-hospital mortality	Average number of patients treated per year, categorised by level of risk Patients in hospitals with less than or more than the mean hospital volume (45)	A variety of demographic, physiological, biochemical and severity variables Patients put into 3 risk categories Standardisation and logistic regression	Overall mortality was 9.1% The SMR for low v high volume hospitals was 1.04 v 0.98 (n.s)
Neonatal Intensive Care						
Field et al (1990)[25] UK	4252 infants who required admission to baby care units of less than or equal to 28 weeks gestation in 17 consultant obstetric units	Prospective cohort design where data was collected on every admission 1987 – 1988	Survival to discharge	Intensive care (IC) units > 500 days of ventilation annually Special care (SC) <500 days of ventilation annually	Birthweight, gestational age, respiratory distress at birth, cephalic or breech presentation, Apgar scores and multiple pregnancy	Infants of ≤ 28 weeks gestation in IC units showed significantly better survival rates than infants treated in SC units (52% v 22%) OR (95% CI) of dying in SC v IC units were 3.98 (1.55 - 10.18) Differences in survival between more mature infants was not significant
Paediatric intensive care						
Pollack et al (1994)[26] USA	5415 pediatric intensive care patients in 16 PICUs	Prospective cohort - medical records of consecutive cases from a random sample following a national survey of all hospitals with PICUs 1989 - 1992	Mortality	ICU volume ranged from 13 patients per month to 63 patients per month	Age, PRISM score and other prognostic factors Logistic linear regression	A non-statistically significant association was found between severity adjusted mortality and volume per month

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	case-mix adjustment	Results
Adult intensive care						
Jones & Rowan (1995)[9] UK	11612 patients over 15 years of age in 26 intensive care units	Data were derived from the Intensive Care Society's UK APACHE II Study year not given	Mortality	The mean monthly volume ranged from 8.3 to 37.7	APACHE II scores Patients divided into surgical and non-surgical Severity standardised mortality ratios	A non statistically significant relation between volume and severity adjusted mortality rates
Prostate						
Wennberg et al (1987)[27] USA	4570 patients undergoing prostatectomy	Retrospective analysis of Medicare and the Manitoba Health Services Commission claims data (and discharge abstracts) 1975 – 1977	Death within 90 days	Annual hospital volume: <40 40 - 90 >90	Age, medical history, cardiovascular diagnoses, nursing home resident, comorbidity, type of operation (open or transurethral) Logistic regression	There was a non statistically significant increase in risk adjusted mortality in hospitals with more than 90 operations v hospitals with less than 40 (odds ratio = 1.26) and hospitals with 40–90 v hospitals with less than 40 (odds ratio = 1.66)
Trauma care						
Waddell et al (1991)[28] Canada	52 trauma victims (of which 89% were blunt trauma in 1 Toronto tertiary care unit 7	Retrospective analysis of the unit's database of outcomes of trauma victims, compared with outcomes from the Multiple Trauma Outcome study 1986 – 1989	Probability of survival, calculated using TRISS methodology	Toronto tertiary care unit (over the 4-year study period the number of patients averaged 15 per month) compared with American trauma care	Injury Severity Score, Trauma Score and Revised Trauma Score Z statistic used to compare survival in the Toronto centre the Multiple Trauma Outcome Study	The overall mortality rate was 15.8% Comparing outcomes in 1986 with outcomes in 1989 (in patients with similar TS and ISS scores) there were no statistically significant differences in outcomes despite a doubling in volume levels
Cataract surgery						
Schein et al (1994)[29] USA	772 Medicare beneficiaries (aged 50+) undergoing first eye cataract surgery by 75 ophthalmologists	Prospective cohort study; ophthalmologists randomly selected (stratified) from 3 sites, reflecting low, medium and high cataract surgery rates 1991	Adverse events and visual acuity (Snellen) at 4-months postoperative	Ophthalmologist volume: Moderate: 51 – 200 High: 201–399: Very high: >400	Age, sex, baseline visual acuity, type of cataract and presence of other eye disease (and any adverse events) Multiple linear or logistic regression	There was no statistically significant association between volume and visual acuity (high volume 0.12 [0.17] and very high volume –0.24 [0.19})
AIDS						
Stone et al (1992)[30] USA	300 AIDS related diagnoses in 40 hospitals	Retrospective analysis of case records from the Massachusetts AIDS Surveillance Programme (population based disease surveillance registry) 1987 – 1988	In-hospital mortality and 30-day mortality	Hospitals were ranked according to annual experience with AIDS patients High experience (HEH): 43 – 229 Low experience (LEH): 1 – 42	The Severity Classification for AIDS Hospitalisations (SCAH) and the Justice Stage Assessment Logistic regression	Being a LEH was a significant predictor of mortality (RR 2.92, 95% CI: 1.37 – 6.22). For 30-day mortality, being a LEH was a predictor (RR 2.51, 95% CI: 1.22 – 5.17)

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	case-mix adjustment	Results
Breast cancer						
Sainsbury et al (1995)[31] UK	12861 women with invasive breast cancer by 180 consultants	Retrospective analysis of a population based cancer registry 1976 –1992	5 year survival	Surgeon volume per year: < 10 10 – 29 30 – 49 >50	Age, stage, tumour grade, socioeconomic status Linear regression	Patients treated by surgeons with caseloads > 29 had significantly better adjusted survival than patients treated by surgeons with caseloads < 10 (risk ratio 0.85, 0.77 – 0.93)
Colon and rectal cancer						
Flood et al (1984)[19] USA	17872 patients with colon cancer in 1040 acute care hospitals	Retrospective analysis of abstract data from the Commission of Professional Hospital Activities and from the Professional Activities Study 1972	In-hospital mortality	Average number of patients treated per year (17.18)	A range of demographic, biochemical, physiological and severity variables Patients put into 3 risk categories Logistic regression	SMRs were 1.14 and 0.94 in low and high volume hospitals, respectively (p<0.05)
Kelly & Hellinger (1986)[16] USA	2612 patients with colorectal cancer in 116 hospitals by 434 physicians	Retrospective analysis of data from the Hospital Cost and Utilisation Project, based on discharge abstract records 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 50.4 (sd 36.4) Mean surgeon volume = 8.4 (sd 5.7)	Age, sex, stage and number of diagnoses Logistic regression	No association between mortality and hospital surgeon volume
Laparotomy with colorectal resection (for cancer and non-cancer diagnoses)						
Sagar et al (1996)[32] UK	438 patients undergoing laparotomy with colorectal resection (some patients had malignancy present) by 5 surgeons	Cohort study where data were collected prospectively by audit clerks and surgeons year not given	Mortality, various complica-tions and anastomotic leak	Surgeon volume ranged from 44 – 110 (period not specified)	POSSUM system was used which includes: physiologic assessment and operative severity score Observed expected outcome	Risk adjusted morbidity and mortality did not differ significantly between surgeons
Stomach cancer						
Kelly & Hellinger (1986)[16] USA	341 patients with stomach cancer in 69 hospitals by 193 physicians	Retrospective analysis of data from the Hospital Cost and Utilisation Project, based on discharge abstract records 1977	In-hospital mortality	Volume treated as a continuous variable Mean hospital volume = 10 (sd 7) Mean surgeon volume = 3 (sd 2)	Age, sex, stage and number of diagnoses Logistic regression	No statistically significant relationship between hospital or surgeon volume and mortality was detected
Oesophageal cancer						
Matthews et al (1986)[34] UK	1143 patients with oesophageal cancer	Retrospective analysis of population based cancer registry 1957 – 1976	Operative & 5 year mortality	Surgeon volume: average number of resections per year: ≤ 3 ≥6	Age, sex, site, histological type of tumour and node involvement, duration of symptoms, curative or palliative resection χ^2 and t-test were used	No statistically significant differences were detected in patient risk factors 39% operative death rate in patients treated by surgeons performing <3 operations v 22% in those with higher volume (p<0.001) Five year mortality was 89% in patients treated by surgeons performing <3 operations vs 85% with higher volumes (p<0.05) After exclusion of operative deaths from the analysis, rates were 82% and 81%, respectively (ns)

Author and country	Procedure and sample size	Design,data source and year of study	Outcomes measured	Volume measure and cut-point used	Case-mix adjustment	Results
Malignant teratoma						
Harding et al (1993)[33] UK	454 males with malignant teratoma in 5 cancer units	Retrospective analysis of population based cancer registry 1975 – 1989	5 year mortality	The comparison was between the centre recruiting the majority of patients (53%) v other centres	Age, time from first symptom to diagnosis, site and volume of disease, disease stage Cox regression	Adjusted mortality was lower in patients treated at the centre with highest recruitment (OR: 0.38 (95% CI: 0.23–0.61)
Pancreatic cancer						
Yeo et al (1995)[35] USA	145 patients with tumour of pancreas, bile duct, ampulla, duodenum undergoing pancreatico-duodenectomy in1 hospital by 5 surgeons	Patients recruited in a RCT of pancreatico gas-trostomy v pancreatico-jejunostomy. Data were collected prospectively 1993 – 1995	Incidence of pancreatic fistula	Surgeon volume over study period: 9 patients 14 17 29 76	Age, sex, race, preoperative history and preoperative laboratory values Patients with different type of cancer or benign tumours were included Logistic regression	Incidence of pancreatic fistula was inversely related to surgeon volume: OR for patients treated by surgeons with: 9 patients (11.62, 95% CI: 1.3–1.06), 14 patients (6, 95% CI: 0.9–41.3), 17 patients (12.96, 95% CI: 2.1–78.3), 29 patients (3.83, 95% CI: 0.7–20.8) against surgeon volume of 76

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